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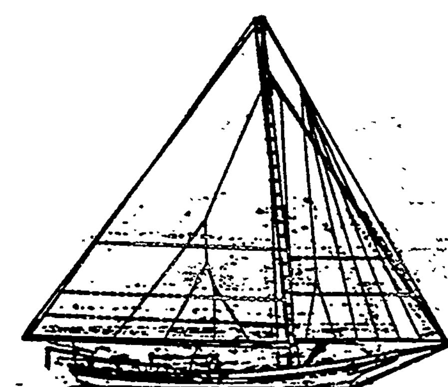

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No. 10

Simulation of Shipyard Material Handling Operations

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ABSTRACT

The initial phase of a two part study to develop a simulation procedure for shipyard material handling operations is described. This phase involved investigation of software alternatives available for simulation, optimization, material handling and data base management. Additionally, material classifications, equipment choice figures of merit and a material handling equipment data base have been developed. The paper presents a discussion of the software investigation and presents choices and rationales to be used in the second phase. Additionally, the format and typical entries in the material handling data base will be presented. A detailed discussion of the final figure of merit equation developed and to be used is also included. Finally, the results of a feasibility study concerning the potential for successful simulation of the problem is presented.

INTRODUCTION

Effective management and control of modern product-oriented shipbuilding systems is based on control and monitoring of material. Work packages are organized around pallets, which are conceptual and physical groupings used for production scheduling and control. Numerous choices of material ordering, fabrication, storage, marshalling and handling systems are possible. Optimal selection from among these choices can significantly impact overall productivity of the shipbuilding process. Simulation modeling is a tool that can be effectively employed to optimize choices in a complex decision making environment. Specifically, for a given objective function, such as total cost, a minimum can be obtained by simulating the results of a series of possible solutions. In this case, the desired solution is a choice of material handling equipment to be used to move particular items from one work station to another. By coupling a simulation of the entire series of moves associated with a shipbuilding or ship repair project, with the computation of the total cost associated with the moves, a least cost assignment of material handling equipment to specific moves can be accomplished. The research reported on here involved the formulation of the procedures and necessary data bases with which to generate a minimum total cost for planned material movement.

DATA BASE DEVELOPMENT

Three data bases are required in order to analyze the material handling choices. These describe (1) the material handling equipment available, (2) the material to be moved, including time and location it is needed for the succeeding work operation, and (3) the facility layout, indicating the work stations to and from which material must be moved. The data bases will provide input data to the simulation model. Therefore, they must contain information in sufficient detail to permit valid analyses to be conducted. They should not, however, contain more detail than can be effectively used in the simulation. The actual flow of the simulation model proposed will be presented later in the paper. However, there are certain prerequisites associated with each of these data bases.

Material Handling Equipment Data Base

The material handling equipment data base must contain information that will enable two major functions to be accomplished. First, the feasibility of using a particular piece of material handling equipment for a given move must be verified. This is a necessary condition for further consideration of the piece of equipment. The feasibility verification requires a determination that the equipment is capable of handling the weight, size and route required for the move. It

also implies that the equipment is not currently being used for another move. The second function involves making an optimum choice of available equipment based on a computation of the cost of using a particular piece of equipment. Since there are likely to be many possible choices, the simulation model should be run making different choices, so that these options can be compared after evaluating total project costs. The data categories for equipment must enable the model to determine these characteristics. Figures 1-5 show the heading categories for the files that comprise this data base. These files are for specific types of material handling equipment, including, bridge/gantry cranes, mobile cranes/crane trucks, jib cranes, transporters/trucks/rail cars, and forklifts. The first two columns are the individual equipment model and name. The next set of columns indicate handling capacities of the equipment. This data can be used to determine the material category classifications for which this piece of equipment may be used. The next column indicates the work station combinations (source and destination) which the equipment can service. The travel speed, used to indicate the length of time required for a given move is included next. This includes both loaded and empty travel speeds.
The type of energy used is provided in the next column. There is also a category, indicated by a code, that directs the user to a file that describes the equipment manufacturer. Figure 6 is an example of this file. The remaining columns contain equipment specific cost data. These costs are described in detail in the section that presents the figure of merit formula.

These files are used to develop a new file, called the potential equipment list. This file is contiuunally updated for each move and over time during the simulation. A more detailed description of the flow of the simulation and the use of this file will be presented later. This file, an example of which is shown in Figure 7, also identifies the piece of equipment by name. It then has a capacity code to indicate the number of items within a material classification that can be handled by this piece of equipment. A column, updated throughout the execution of the simulation indicates the status of the equipment, including available, in use, or down. Another column indicates the location status, i.e. where a piece of equipment is located in the facility at a given time. This information is also updated during the simulation. Finally, a series of columns indicate the cost categories, including labor, energy, maintenance, down time, purchase, installation anti debt service costs. The last column is one total cost associated with the use of a given piece of equipment up to the current time in the project (for a given simulation run). Note that while most of the data categories are constants, some are variables that are updated during the simulation and some may be stochastic, i.e. represented by a distribution. These variables are evaluated using typical random number generators during the running of the simulation. The optimization, equation, used to compute total cost, is shown later in the paper.

Material Class Data Base

Since the number and variation of individual items to be moved during a shipbuilding or major ship repair/overhaul project is extensive, a means of limiting the size of this data base to manageable proportions is required. In order to accomplish this, a material classification scheme is used. This scheme employs ten major classes, with the ability to subdivide the classes into sub-categories based on the specifics of the material handling problem. The classes include:

1. Structural raw materials
2. Outfitting raw materials
3. Pipe and tubing fittings and valves
4. Electrical system components
5. Hull and superstructure components
6. Fastening materials
7. Motors and pumps
8. Major equipment
9. Sheet metal components
10. Miscellaneous materials

The specific sub-categories within these major equipment categories are shown in the table in the appendix. Also, in addition to these categories, the data base must handle five assembly stage outputs, including sub-assemblies, outfit units, sub-blocks, blocks, and grand blocks. These outputs are primarily identified by the material handling constraints, including size, weight and special considerations [1,2]. .

Facility Layout Data Base

This data base is a direct function of the simulation software to be used. Most manufacturing simulation software packages include a simple structure for input of the facility layout. Consequently, no specific recommendations on the format of the layout input is made in this phase of the research. Following development of a case study of the material handling

Model	Name	Maximum Moving Capacity (ton)	Bridge Span (ft)	Moving Distance (ft)	Under Bridge (ft)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No	Labor Cost ($/hr)	Energy Cost ($/hr)	Maint Cost $	Emergency Down Cost ($)	Purchase Cost ($)
TDC	TDC1	3.00	25.00					E	1					
(top	TDC2	3.00	45.00					E	1					
running)	TD13	3.00	60.00					E	1					
	TDC4	5.00	25.00					E	1					
	DTC5	5.00	45.00					E	1					
	TDC6	5.00	60.00					E	1					
	TDC7	7.50	25.00					E	1					
	TDC8	7.50	45.00					E	1					
	TDC9	7.50	60.00					E	1					
	TDC10	10.00	25.00					E	1					
	TDC11	10.00	45.00					E	1					
	TDC12	10.00	60.00					E	1					
	TDC13	15.00	25.00					E	1					
	TDC14	15.00	45.00					E	1					
	TDC15	15.00	60.00					E	1					
USG	USG1	1.00	12.50					E	1					
(under	USG2	1.00	30.00					E	1					
running)	USG3	1.00	40.00					E	1					
	USG4	2.00	12.50					E	1					
	USG5	2.00	30.00					E	1					
	USG6	2.00	40.00					E	1					

Install Cost ($)	Interest Cost ($)

Figure 1 Bridge/Gantry Cranes

Model	Name	Capacity (ton)	Under Boom (ft)	Span (ft)	Maximum Height (ft)	Rotation (degree)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No.	Labor Cost ($/hr)	Energy Cost ($/hr)	Maint Cost $
200-BPM	2001	0.25	10.00	8.00	10.58	360			E	1			
	2002	0.25	10.00	14.00	10.75	360			E	1			
	2003	0.25	10.00	20.00	10.92	360			E	1			
	2004	0.25	12.00	8.00	12.58	360			E	1			
	2005	0.25	12.00	14.00	12.75	360			E	1			
	2006	0.25	12.00	20.00	12.92	360			E	1			
	2007	0.50	10.00	8.00	10.58	360			E	1			
	2008	0.50	10.00	14.00	10.92	360			E	1			
	2009	0.50	10.00	20.00	11.08	360			E	1			
	2010	0.50	12.00	8.00	12.58	360			E	1			
	2011	0.50	12.00	14.00	12.92	360			E	1			
	2012	0.50	12.00	20.00	13.08	360			E	1			
	2013	1.00	10.00	8.00	10.75	360			E	1			
	2014	1.00	10.00	14.00	11.08	360			E	1			
	2015	1.00	10.00	20.00	11.33	360			E	1			
	2016	1.00	12.00	8.00	12.75	360			E	1			
	2017	1.00	12.00	14.00	13.08	360			E	1			
	2018	1.00	12.00	20.00	13.33	360			E	1			
	2019	1.50	10.00	8.00	10.92	360			E	1			
	2020	1.50	10.00	14.00	11.08	360			E	1			
	2021	1.50	10.00	20.00	11.58	360			E	1			

Emergency Down Cost ($)	Purchase Cost ($)	Install Cost ($)	Interest Cost ($)

Figure 2 Mobile Cranes/Crane Trucks

Model	Name	Maximum Lifting At Max. Radius (ft)	Maximum Lifting At Min Radius (ft)	Rotation Degree	Mobile Method: tire rail, crawler	Highest Working Point Of Hook (ft)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No.	Labor Cost ($/hr)	Energy Cost ($/hr)	Maint Cost $	Emergency Down Cost ($)	Purchase Cost ($)	Install Cost ($)	Interest Cost ($)
	3911001									3							
	3911002									3							
	3911003									3							
	3911004									3							
	3911005									3							
	3911006									3							
	3911007									3							
	3911008									5							
	3911009									5							
	3911010									5							
	3911011																
	3911012									3							
	3911013									3							
	3911014									3							
	3911015									3							
	3911016																
	3911017																
	3911018									5							
	3911019									5							
	3911020																
	3911021																

Figure 3 Jib Cranes

Model	Name	Maximum Load Capacity (ton)	Width Of Platform (ft)	Length OF Platform (ft)	Height OF Platform (ft)	Width OF Equip (ft)	Length Of Equip (ft)	Minimum Turning Radius (ft)	Mobile Require. tire, rail, crawler	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No.	Labor Cost ($/hr)	Energy Cost ($/hr)	Maint Cost $	Emergency Down Cost ($)	Purchase Cost ($)	Install Cost ($)	Interest Cost ($)
	3906001												7							
	3906002												7							
	3906003												7							
	3906004												7							
	3906005												7							
	3906006												7							
	3906007												7							
	3906008												7							
	3906009												7							
	3906010												7							
	3906011												7							
	3906012												7							
	3906013												7							
	3906014												7							
	3906015												7							
	3906016												7							
	3906017												7							
	3906018												7							
	3906019												7							
	3906020												7							
	3906021												7							

Figure 4 Transporters/Trucks/Rail Cars

Model	Name	Max Lift Capa (ton)	Max lift Ht (in)	Maximum Moving/ Reaching Capacity (ton)	Width Of Truck (in)	Length Of Truck (in)	Outside Turning Radius (in)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Load Type: forward, backward	Road: special, hard, normal, any	Energy Type	Manu Code No.
GLC 040A	GL1	4.00	100.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL2	4.00	140.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL3	4.00	148.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL4	4.00	168.00		38.10	82.90	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL5	4.00	213.00		38.10	82.90	71.90	9.30	9.90	F	Tire	Gas	2
GP090H/GLP	GP1	9.00	96.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP2	9.00	116.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP3	9.00	136.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP4	9.00	176.00		56.10	134.00	112.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP5	9.00	206.00		56.10	134.00	112.20	13.40	14.90	F	Tire	Gas	2
GC 100L	GC1	10.00	96.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC2	10.00	116.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC3	10.00	136.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC4	10.00	139.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC5	10.00	146.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC6	10.00	176.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC7	10.00	206.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2

Labor Cost ($/hr)	Energy Cost ($/hr)	Maint Cost $	Emergency Down Cost ($)	Purchase Cost ($)	Install Cost ($)	Interest Cost ($)

Figure 5 Forklifts

MFG CODE	MFG NAME	MFG TELEPHONE	MFG ADDRESS
1	STANSPEC CORP.	(216) 451-8900	13600 Deise Avenue Cleveland, Ohio 44110.
2	YALE	(206) 762-1777	Northwest, Inc. 7001 N.E. Columbia Boulevard, Portland OR 97218.
3	ACCO	(717) 843-1523	1110 East Princess Street, York, Pennsylvania 17403.
4	HARRINGTON	(800) 233-3010	401 West End Avenue, Manheim, PA 17545.
5	BAKER	(800) 627-1700	1 South Idaho Street, P.O. Box 3581, Seattle, WA 98124.
6	CUSHMAN	(800) 228-4444	P.O. Box 82409, Lincoln, NE 68601.
7	INDUSTRIAL CRANE & EQUIP. CO.	(312) 378-0100	4701 West Iowa Street, Chicage, IL 60651.
8	CLYDE	(218) 722-7451	29th Avenue West & Michigan Street, Duluth, Minnesota 55806.
9	AMERICAN HOIST & DERRICK CO.	(612) 293-4567	63 South Robert Street, St Pul, Minnesota 55107.
10	AUTO CRANE COMPANY	(918) 438-2760	PO Box 581510, Tulsa, Oklahoma 74158.
11	LORAIN	(414) 873-3400	PO Box 422, Milwaukee, WI 53201.
12	NATIONAL CRANE	(402) 786-2240	11200 North 148th Street, Waverly, Nebraska 68462.
13	MITSUI ZOSEN (USA) INC.	(212) 308-3350	Suite 501, 405 Park Avenue, New York, NY 10022
14	GROVE	(717) 597-8121	PO Box 21, Shady Grove, Pennsylvania 17256.
15	HIAB CRANES & LOADERS INC.	(302) 328-5100	Airport Ind. Pk., 258 Quigley Blvd., New Castle, DE 19720.
16	MULTILIFT	(800) 821-9966	2000 S. Cherokee, Denver, Colorado 80223.
17	RPC CORP	(919) 599-3141	PO Box 451, Roxboro, North Carolina 27573.
18	STELCO INC.	(913) 287-1500	5500 Kansas Avenue, Kansas City, KS 66106.
19	LINK BELT	(312) 295-5500	2800 Lakeside Drive, Bannockburn, Illinois 60015.
20	NEI CLARKE CHAPMAN LTD.	(091) 477-1009	Victoria Works, Gateshead, Tyne & Wear NE8 3HS, UK.
21	WASHINGTON CRANES	(205) 622-4421	2925 First Avenue South, seattle, Wa 98134.

Figure 6 Manufacturers

Name	Capac Code	Location Status	Usage Statu	Labor Cost $/hr	Energy Cost $/hr	Maint Cost $	mergency Down Cost $	Purchase Cost $	Install Cost $	Interest Cost $	Total Cost $

Figure 7 Potential Equipment List

simulation (phase II of the research), the specifics of inputting the layout will be explained.

SOFTWARE CHOICES

Data Base Management

The choice of software to be used in developing the data bases was made based on two primary factors. These are the ability of the data base software to perform the necessary functions, and the transferability of the software between shipyards. Consequently, a relatively powerful data base handling software package is required. Additionally, it must be a system that is readily available or already in common use. One such software system that satisfies these requirements is LOTUS 1-2-3 [3].

LOTUS 1-2-3 offers a typical spreadsheet approach to data base management. The software is readily available for PC operation on most commonly used machines. It provides ample space for the major data bases required, offering 256 columns and 8192 rows for data entry. The information required per piece of material handling equipment is considerably less than the 256 column capacity. Similarly, shipyards are not likely to have in excess of 8192 individual pieces of material handling equipment to be managed and scheduled. The spreadsheet format is one with which most computer users are familiar. It is also quite powerful, providing considerable computational and sorting capability.

Simulation

There are many manufacturing simulation software packages available for consideration for use in optimizing material handling. Summaries of these packages are generally presented and updated annually by a number of journals, including INDUSTRIAL ENGINEERING [4] and MODERN MATERIALS HANDLING [5]. More than 50 such software packages are currently on the market. Consequently, choices cannot be made based on trials of these various packages. Again, simple criteria must be applied and choices made. The major criteria are flexibility, capability, availability and relative cost. Use of packages that are commonly used and readily available is prudent. Given this need to make a choice without the benefit of comparative testing, this recommendation is based on availability and common use. Most simulation packages that have been developed for manufacturing application using PCs are capable of dealing with the problem to be addressed in this research. Of the packages available, SLAM II, perhaps with the graphical add on package TESS is recommended [6]. This software is commonly available, has been used in numerous applications and is backed by an on-going support service. It is relatively easy to use and has both the power and flexibility needed to develop a material handling optimization simulation program for a shipyard.

Should an individual shipyard have another standard simulation package available, switching from SLAM II should be relatively easy using the model developed in this and the second phase of the research.

OPTIMIZATION/SIMULATION FEASIBILITY

The actual material handling simulation and optimization program will require the development of a number of parts. These can be subdivided into optimization and simulation. The optimization is based on the development of a "figure of merit" or total cost formulation. The feasibility of conducting the simulation will be addressed by considering the data required, the outputs expected, and by developing a flow chart of the simulation procedure.

Figure of Merit Formula

In order to evaluate optional choices of material handling equipment, a figure of merit (cost) formulation must be developed. Using this formula, applied to each move and the associated piece of material handling equipment used, a total cost of material handling equipment choices can be determined for a given plan. The total cost of various plans can then be compared. The cost formula computes cost in four basic categories. These include the labor cost associated with the use of a given piece of material handling equipment, the energy cost, the cost associated with "emergency" or unanticipated breakdowns of the equipment, and the cost of having the equipment available, including purchase, depreciation, scheduled maintenance, etc. These costs are combined on either an hourly use rate or over a total projected project duration and then summed for the project. The figure of merit formulation is given below.

Total Cost ($ /Project) =

SUM over all moves [labor cost * actual working time (hrs)
+ energy cost * actual working time (hrs)
+ emergency breakdown cost
+ ((purchase cost = installation cost)
* depreciation coefficient + interest cost
+ maintenance cost) * project utilization coefficient (partial yearly usage of equipment on a specific project)]

where:

Labor Cost (S/hr) = Number of operators
* Average wage/hour/operator

actual working time = travel time + load time + unload time

Energy Cost (S/hr) = Cost per unit of energy type used
* energy consumption at maximum output per hour
* energy utilization coefficient

Maintenance Cost (S) = Constant or stochastic (distribution)

Emergency Breakdown Cost (S) = (1 - reliability coefficient)
* (delivery delay cost per/hr
+ inventory COSt per hour
+ overtime cost per hour
+ idle time cost per hour;
* repair time (hrs) ,
stochastic (distribution)

Purchase Cost (S) = constant

Installation cost ($) = direct installation cost
+ area utilization cost
+ additional facility (building) construction cost

Interest Cost (S) = (purchase cost + installation cost) * interest rate

The constant values must be input to the individual shipyard material handling equipment data base. Given these data, the simulation can then be run to provide a means of evaluating alternative choices of material handling equipment usage and scheduling. Note that in the total cost equation, labor and energy costs for a particular 'piece of equipment and a specific move must include unloaded moves (if required) to position the equipment where it is needed. The simulation model will account for this requirement. Additionally, capital costs (purchase and installation), must be based on present value computations.

Simulation Approach

The simulation is used to provide and compare material handling equipment choices and schedules. Initially, the overall project schedule must be defined by work and material category. In effect, a combined graph of work control parameter versus time is required for each work station pair, i.e. source and destination, involved in material movement [7,8]. This will be nearly every work station. The major exceptions will be work stations that are directly linked to succeeding or preceding work stations, such as a panel line. Here there is no material handling choice since there is a direct connection and most likely dedicated equipment for material handling. For the remainder, the graphs are as shown in Figure 8. The predominant parameter, as in product oriented scheduling, is weight. However, where other parameters are used, such as number of pipe piece connections, a parameter to relate the work schedule to the material handling schedule is required. The material classification categories previously defined will be used here.

Given this material handling schedule to support the master production schedule, the simulation may begin. The inputs to the simulation from the material handling schedule are the feasible material handling equipment for each move, the distance of each move, and the handling weights per material category for each move. my piece of material handling equipment that is in the feasible data file may be ready to be used at the beginning of a working period, or only

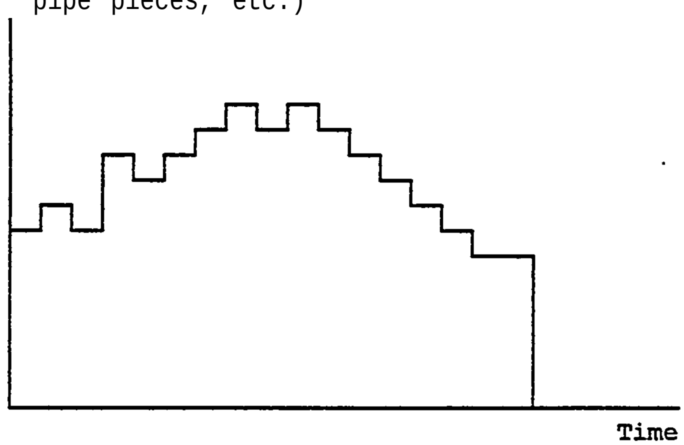

Figure 8 Material Movement Schedule

for some portion of that period. The equipment may need to be moved empty to the required work station, and it may be used for a single move, or for a series of moves in sequence. Similarly, materials to be moved may be ready and prepared to be moved at a given point in time, or a distribution of probability of it being ready can be used.

The simulation is then run. It will produce outputs which define the piece of material handling equipment utilized for each move, the utilization time for each piece of equipment, and any delays associated with either lack of availability of material handling equipment or materials to be moved. Based on these outputs, the total cost for the project of that option can be computed. A simplified flow chart for this simulation is shown in Figure 9. The primary feedback loops are from the simulation to the potentially useable equipment data file, to update and choose for the next move scheduled, and from the analysis and result storage back to the potentially useable equipment file to run a new simulation of the project. A series of simulation runs can be compared to choose a least total cost material handling equipment utilization schedule.

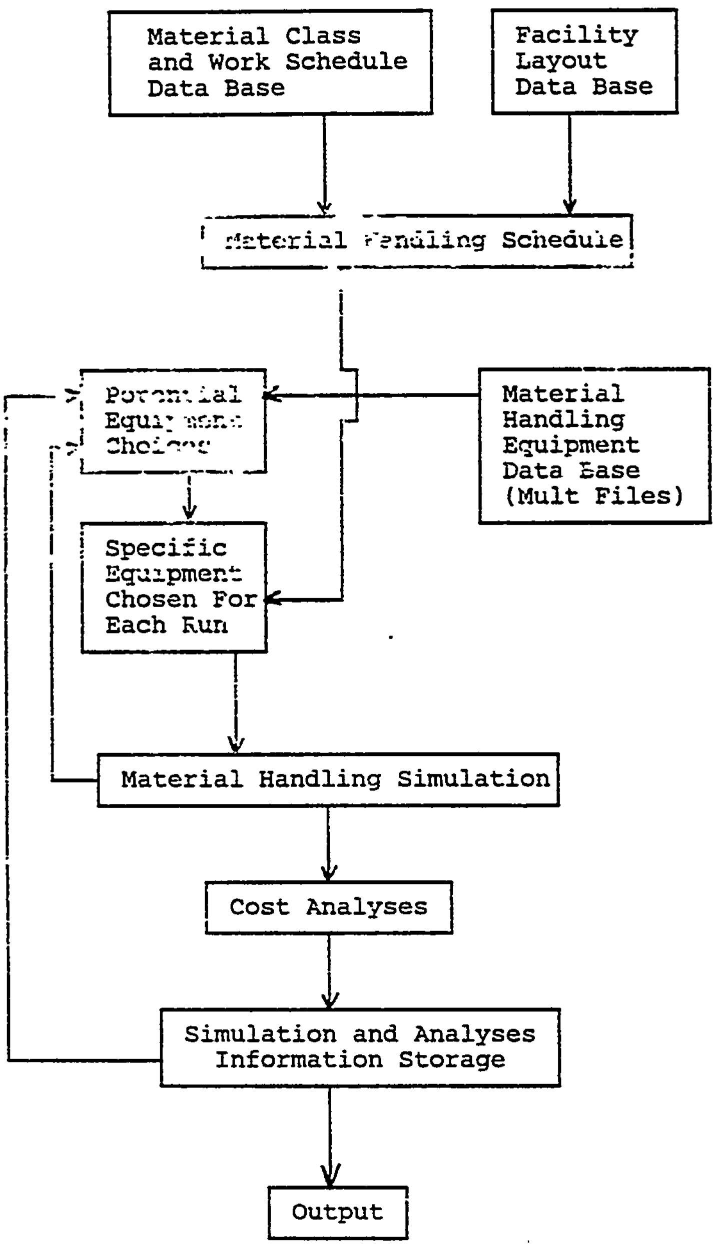

Figure 9 Simulation and Optimization Flow Chart

A significant consideration in this proposed simulation is the method of choosing a piece of equipment for a specific move. Two suggestions are presented and will be incorporated in the final model. First, manual (possibly interactive) selection is recommended. In effect, this is the way moves are currently scheduled in most shipyards. The manager of the department responsible for providing material handling equipment commonly uses some combination of a schedule and immediate requests to make short term decisions and assignments. The model should therefore permit this expertise to be applied to provide a starting point. The simulation can then be run to evaluate this proposal and to generate similar but alternative approaches. The second approach is to automate these decisions based on a set of heuristics. The model will employ such a set of heuristics, but in actual use, each manager should have the opportunity to adjust the heuristics to suit an individual shipyard's needs and capabilities. These two approaches can be combined, either by providing interactive override of heuristic choices by the manager, or by using the heuristics to develop alternate schedules based on the initially input material handling equipment utilization schedule.

Simulation Feasibility

There are two primary issues of feasibility. The first involves the size and therefore running time of the model. The use of material categories and the scheduling parameters is a means of limiting the size of the simulation model. There are fifteen material categories, including the ten for specific individual material items, plus the five assembly categories. There are likely to be between 15 and 30 work station locations required to model the production process. This size model should be well within the capabilities of the PC based version of SLAM II recommended for use. Additionally, the material handling equipment data base should not be difficult to develop or handle. Similarly, the project schedule, if appropriately developed using the schedule parameter approach should also not be too large or cumbersome to handle. Clearly, the movement of every single item is not intended to be incorporated in the model. Rather, preplanned moves of equipment, manufactured parts and assemblies between work stations only are evaluated by this model. Thus the large frame material handling issues are involved. Subject to project specific needs, however, the model can be used to evaluate "critical" moves no matter what category (including size, weight, etc.) material is involved. Therefore, preplanning of moves is a prerequisite to the use of the model. The simulation model should be an effective tool to evaluate changes from the plan and to alter the material handling schedule to deal with such changes.

The second feasibility issue is more difficult to analyze prior to actually attempting to develop the model. This involves the heuristics development for making individual equipment choices. Heuristics can be extremely difficult to develop. This seems to become a more significant problem as they more closely model the actual decision process employed by an experienced decision-maker. In developing the simulation model, less meaningful but simple heuristics can be a useful starting point. The accuracy (utility) of the heuristics can then be increased incrementally until they are either satisfactory or the efficiency of the model begins to deteriorate significantly. While there is no assurance that such a set of heuristics can be obtained, the increasing success of such simulation modeling in other manufacturing environments provides some optimism [9, 10, 11].

OTHER USES OF THE MODEL

There are a number of possible uses for the model proposed in this paper. The two primary areas of use involve material handling equipment decisions and scheduling. In the first area, the model should be effective in two significant areas. First, decisions on buying and selling material equipment can be justified by running the model with the material handling equipment data base appropriately changed. Benefits in cost and schedule will be readily apparent. Additionally, maintenance and breakdown records can be used to improve the accuracy of the data base, and then can be used to improve the scheduling of maintenance and prediction of breakdowns.

In the area of project scheduling, the model can be used to consider the impacts of schedule changes on material handling requirements and costs. Such an analysis can highlight bottleneck operations and therefore permit critical review of the manufacturing system. Similarly, the model can be used to evaluate the shipyard layout, and to provide material handling cost figures for layout alterations. The use of manufacturing simulation in other industries has lead to improvements in system problem identification and solution. This includes not only scheduling, equipment and layout, but also quality, batch size, labor utilization, etc. It is this author's belief that simulation holds similar promise for shipyard operations improvement.

CONCLUSIONS

This paper reports on the first phase of a two phase research project concerning the use of simulation to aid in the choice of material handling equipment for use in a shipbuilding or ship repair/overhaul project. The paper describes the results of attempts to carefully formulate the problem, both to indicate the data required and to evaluate the feasibility of producing software that would be-useful to shipyard material handling department managers. Although only completion of phase II of the project can definitely establish the viability of simulation to solve this problem, the author is encouraged by these results. Additionally, while the size and scope of shipyard projects represents a significant problem in utilizing simulation, it appears possible to handle a problem of this size, if it is formulated in the manner recommended. A key factor, as in any simulation, is the accuracy of input data. In particular, schedule and work progress parameter data must be valid in order to produce valid simulation results. Despite this potential difficulty, the use of simulation shows considerable promise as a tool to help reduce costs and improve planning of material handling operations in a shipyard.

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APPENDIX

Major Equipment Sub-catagories

Group 1: Structural Raw Materials

ITEM	NASSCO NO.	BIW NO.
Steel (plates and shapes)	82	40,41
Stainless Steel	83	-
CRES and non-Ferrous (Except Aluminium) Plates and Sheets	-	42
CRES, Tool Steel and non-Ferrous (Except Aluminum) Bars and Shapes	-	43
Other Steel. Includes: Chrome-Moly, CU-Ni, Brass, etc.	84	-
Manufactured Bill of Material Items (Tees, Angles)	85	-
Metal (Ingots, Ores)	86	-
Steel Inventory (Flat Bar, Round Bar, Small Shapes, etc.)	88	-
Miscellaneous Surplus Steel	89	-
Spec. Material	90	-
Spec. Material	91	-
Spec. Material	92	-
Castings and Forgings		44
Aluminum (Plates and Shapes)	81	55,56

Group 2: Outfitting Raw Materials

ITEM	NASSCO NO.	BIW NO.
Pipe, Steel, ASTM A53	01	10
Pipe, Steel, ASTM A106, Chrome-Moly, Stainless Steel	02	10
Pipe, Aluminum, Copper, Brass, CU-NI, Misc.	03	10
Pipe, Plastic, Polyethylene, Nylon	04	10
Tubing, Stainless Steel	05	10
Tubing, Steel Carbon	06	10
Tubing, CU-NI, 90-10	07	10
Tubing, CU-NI, 70-30	08	10
Tubing, Copper, Brass, Misc.	09	10

Group 3: Pipe and Tubing Fittings and Valves

ITEM	NASSCO NO.	BIW NO.
Adapters, bushings, nipples	10	13,14
Caps, plugs, locknuts	11	13,14
Couplings, connectors	12	13,14
Elbows, 45°	13	13,14
Elbows, 90°	14	13,14
Flanges, expansion joints	15	15
Reducers, returns, inserts	16	13,14
Crosses, tees, laterals, branches	17	13,14

Unions	18	13,14
Deck drains, deck plates, refrigerator space drains	19	13,14
General plumbing fixtures and fittings includes: faucets, spouts, flush valves, "p" traps, water closets, etc.	20	18
Sockolets, elbolets, brazolets, nipolets, weldolets thredolets, latrolets, bosses, chill rings, couplets, tube fittings	21	
Tube fittings	22	13,14
Separators, traps, strainers, air-eliminators, filters, flame arrestors	23	
Gauges and gauge valves, liquid level and sight flow indicators, meters, regulators, thermometers, etc.	24	16,20
Aeroquip fittings and hose	25	20
Mechanical telegraph and voice tube fittings	27	17
Hose and hose fittings, emergency fresh air breathing apparatus, fire extinguishers, gas masks	29	
Angle valves	30	11,12
Butterfly valves	31	11,12
Measurflo control valves, liquid level control valves, temperature and pressure control valves, pressure reducing valves, solenoid valves	32	11,12
Gate valves	33	11,12
Globe valves	34	11,12
Cock valves	35	11,12
Relief valves	36	11,12
Check valves	37	11,12
Manifolds	38	11,12
Other valves includes: ball valves, scupper valves, eductors, vent terminal valves, vent check valves, plug valves, blow-off valves	39	11,12

<u>Group 4: Electrical</u>

ITEM	NASSCO NO.	BIW NO.
Cable and wire	60	25,26,27
Fittings and supplies, includes: packing assembly, wave guide bends, terminal blocks, connectors, caps, conduits, fuses, terminals, stiffing tubes, etc.	61	28,30
Connector boxes, flourescent light fixtures	62	
Plastic tape, braid	63	
Lighting (lamps)	64	28
Miscellaneous electric	65	
Coils and relays	66	
Switches and controllers, includes: circuit breakers	67	37
I.C. Equipment and parts	68	31,32
Navy symbol electrical, includes: feeder distribution boxes, fuse boxes, jack boxes, switch boxes, terminal boxes, indicator lights, light panels, receptacles, switches, pressure transducers, etc.	69	29,30
Wave grids and fittings		33
Power generation and transformation equipment		34
Instruments, electrical/electronics		35
Electronic compounds		38

<u>Group 5: Hull and Superstructure Components</u>

ITEM	NASSCO NO.	BIW NO.
Deck cleats, chocks, fairleads, hawse pipe material	40	
Blocks, sheaves	41	

Rigging material includes: clevis, hooks, shackles, snaps, links, turnbuckles, etc.	42	
Doors and closures	44	
Furniture and fixtures	45	
Anchoring device, stair treads, railing, gratings, etc.	48	
Laundry, barber shop, galley, messing and scullery equipment		4
Lumber	73	45
Medical and laboratory equipment and supplies		69
Office equipment, furniture, supplies and ships outfit	79	71
Coverings, floor and deck		73

Group 6: Fastening Materials

ITEM	NASSCO NO.	BIW NO.
Bolts and studs	50	53
Nuts	51	53
Pins	52	53
Rivets	53	53
Screws	54	53
Washers	55	53
Weld rod, flux, solder	56	61
Tools	78	80,81,82
Misc., includes: hangers, uristruts, clamps, sway braces	57	54
Gear and shifting boxes, couplings for flex shaft and rigid rods	59	
Rope, thread, chain, twine, and wire (non-electrical)	43	50

Group 7: Motors and Pumps

ITEM	NASSCO NO.	BIW NO.
Motors		90
Pumps		91

Group 8: Major Equipment

ITEM	NASSCO NO.	BIW NO.
Major equipment - Hull	94	97
Major equipment - Machinery	96	98
Major equipment - Electrical	93	99

Group 9: Sheet Metal Components

ITEM	NASSCO NO.	BIW NO.
Vent fittings		3
Air-Conditioning units and supplies, heaters, vent fittings, and ducting includes: intake and exhauset bellmouths, thermostats, spiral fittings, access covers, regulators, diffusers, ventillators, grills	28	93

Group 10: Miscellaneous Materials

ITEM	NASSCO NO.	BIW NO.
Chemicals, grease, oil, gases	70	60,62,63,64
Compounds, includes: adhesive, cement, epoxy, etc.	71	49
Government furnished material	74	
Paint	47	48
Insulation	46	57,47
Cleaning supplies		72
Finishing, decorative materials and accessories		74
Vendor service items		86
Fabrics, plastics, glass, tapes		46
Safety and protective equipment		70

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